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IN

CHEMICAL GEOLOGY,

BY T. STERRY HUNT, M.A., F.R.S.,

OF THE GEOLOGICAL COMMISSION OF CANADA.

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SOME POINTS IN CHEMICAL GEOLOGY,*

BY T. STERRY HUNT, M.A., F.R.S.

I. In a paper read before the American Association at Montreal in August 1857, as also in some previous communications to the Royal Society, and in the Report of the Geological Survey of Canada for 1856, I have endeavoured to explain the theory of the transformation of sedimentary deposits into crystalline rocks. In considering this process we must commence by distinguishing between the local metamorphism which sometimes appears in the vicinity of traps and granites, and that normal metamorphism which extends over wide areas, and is apparently unconnected with the presence of intrusive rocks. In the former case, however, we find that the metamorphosing influence of intrusive rocks is by no means constant, showing that their heat is not the sole agent in alteration, while in the latter case different strata are often found affected in very different degrees; so that fossiliferous beds but little altered are sometimes found beneath crystalline schists, or even intercalated with them.

We cannot admit that the alteration of the sedimentary rocks has been effected by a great elevation of temperature, approaching, as many have imagined, to that of igneous fusion; for we find unoxidized carbon, in the form of graphite, both in crystalline lime-

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stone and in beds of magnetic iron-ore; and it is well known that these substances, and even the vapour of water, oxidize graphite at a red heat, with formation of carbonic acid or carbonic oxide. I have however shown that solutions of alkaline carbonates in presence of silica and earthy carbonates slowly give rise to silicates, with disengagement of carbonic acid, even at a temperature of 212° Fahr.,— the alkali being converted into a silicate, which is then decomposed by the earthy carbonate, regenerating the alkaline salt, which serves as an intermedium between the silica and the earthy base. I have thus endeavoured to explain the production of the various silicates of lime, magnesia and oxide of iron so abundant in crystalline rocks, and with the intervention of the argillaceous element, the formation of chlorite, garnet and epidote.[†] I called attention to the constant presence of small portions of alkalies in insoluble combination in these silicates, both natural and artificial—a fact which had already led Kuhlmann to conclude that alkaline silicates have played an important part in the formation of many minerals; and I suggested[‡] that, by combining with alkalies, clays might yield feldspars and micas, which are constantly associated in nature with the silicates above mentioned. This suggestion has since been verified by Daubrée,[§] who has succeeded in producing feldspar by heating together for some weeks to 400° C. mixtures of kaolin and alkaline silicates in the presence of water.

The problem of the generation from the sands, clays and earthy carbonates of sedimentary deposits, of the various silicious minerals which make up the crystalline rocks, may now be regarded as solved, and we find the agent of the process in waters holding in solution alkaline carbonates and silicates, acting upon the heated strata. These alkaline salts are constantly produced by the slow decomposition of feldspathic sediments, and are met with alike in the waters of the unaltered Silurian schists of Canada, and of the secondary strata of the basins of London and Paris. In the purer limestones however, the feldspathic or alkaliferous elements are wanting; and

[†]Proceedings of the Royal Society, May 7, 1857.
[‡]Report Geol. Surv. Canada, 1856, p. 479.
[§]Bull. Soc. Géol. de France (2) vol. xv. p. 103.

these strata often contain soluble salts of lime or magnesia. These would neutralize the alkaline salts, which infiltrating from adjacent strata, might otherwise effect the transformation of the foreign matters present in the limestones into crystalline silicates. By a similar process these calcareous or magnesian salts, penetrating the adjoining strata, would retard or prevent the alteration of the latter. These considerations will serve to explain the anomalies presented by the comparatively unaltered condition of some portions of the strata in metamorphic regions.||

II. As the history of the crystalline rocks becomes better known, we find that many which were formerly regarded as exclusively of plutonic origin are also represented among altered sedimentary strata. Crystalline aggregates of quartz and feldspar with mica offer transitions from mica-schist, through gneiss, to stratified granites, while the pyroxenic and hornblendic rocks of the altered Silurian strata of Canada pass, by admixtures of anorthic feldspars, into stratified diorites and greenstones. In like manner the interstratified serpentines of these regions are undoubtedly indigenous rocks, resulting from the alteration of silico-magnesian sediments, although the attitude of the serpentines in many countries has caused them to be ranked with granites and traps, as intrusive rocks. Even the crystalline limestones of the Laurentian series, holding graphite and pyroxene, are occasionally found enveloping broken beds of

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|| De Senarmont[1] in his researches on the artificial formation of the minerals of metalliferous veins by the moist way, has shown that by aid of heated solutions of alkaline bicarbonates and sulphurets, under pressure at temperatures of 200° or 300° C., we may obtain in a crystalline form many native metals, sulphurets, and sulpharseniates, besides quartz, fluor-spar and sulphate of barytes.

Daubrée[2] has since shown that a solution of a basic alkaline silicate deposits a large portion of its silica in the form of crystalline quartz when heated to 400° C. We have here, beyond a doubt, a key to the true theory of metalliferous veins. The heated alkaline solutions, which are at the same time the agents of metamorphism, dissolve from the sediments the metallic elements which these contain disseminated, and subsequently deposit them with quartz and the various spars in the fissures of the rock.

[1] Ann. de Chim. et de Phys. (3), vol. xxxii, p. 129,
[2] Bull. Soc. Géol. de France (2), vol. xv, p. 99.

quartzite, or injected among the fissures in adjacent silicious strata. From similar facts, observers in other regions have been led to assign a plutonic origin to certain crystalline limestones. We are thus brought to the conclusion that metamorphic rocks, such as granite, diorite, dolerite, serpentine, and limestone, may under certain conditions, appear as intrusive rocks. The pasty or semi-fluid state which these rocks must have assumed at the time of their displacement is illustrated by the observations of Daubrée upon the swelling up of glass and obsidian, and the development of crystals in their mass under the action of heated water, indicating a considerable degree of mobility among the particles. The theory of igneo-aqueous fusion applied to granites by Poulett Scrope and Scheerer, and supported by Elie de Beaumont and by the late microscopic observations of Sorby, should evidently be extended to other intrusive rocks; for we regard the latter as being in all cases altered and displaced sediments.

III. The silico-aluminous rocks of plutonic and volcanic origin are naturally divided into two great groups. The one is represented by the granites, trachytes and obsidians, and is distinguished by containing an excess of silica, a predominance of potash, and only small portions of soda, lime, magnesia and oxide of iron. In the other group silica is less abundant, and silicates of lime, magnesia and iron predominate, together with anorthic feldspars, containing soda and but little potash. To account for the existence of these two types of plutonic rocks, Prof. J. Phillips supposes the fluid mass beneath the earth's crust to have spontaneously separated into a lighter, silicious, and less fusible layer, overlying a stratum of denser basic silicates. In this way he explains the origin of the supposed granitic substratum, of the existence of which however, the study of the oldest rocks affords no evidence. From these two layers, occasionally modified by admixtures, and by partial separation by crystallization and eliquation, Prof. Phillips suggests that we may derive the different igneous rocks. Bunsen and Durocher have adopted, with some modifications, this view; and the former has even endeavoured to calculate the composition of the normal trachytic and pyroxenic magmas (as he designates the two supposed zones of fluid matter underlying the earth's crust), and then seeks,

from the proportion of silica in any intermediate species of rock, to deduce the quantities of alkalies, lime, magnesia and iron which this should contain.

So long as the trachytic rocks are composed essentially of orthoclase and quartz, and the pyroxenic rocks of pyroxene and labradorite, or a feldspar approaching it in composition, it is evident that the calculations of Bunsen will to a certain extent hold good; but in the analyses, by Dr. Streng, of the volcanic rocks of Hungary and Armenia, we often find that the actual proportions of alkalies, lime, and magnesia vary considerably from those deduced from calculation. This will necessarily follow when feldspars like albite or anorthite replace the labradorite in pyroxenic rocks. The phonolites are moreover highly basic rocks, which contain but very small amounts of lime, magnesia, or iron, being essentially mixtures of orthoclase with hydrous silicates of alumina and alkalies.

IV. In a recent enquiry into the probable chemical conditions of a cooling globe like our earth, I have endeavoured to show that in the primitive crust all the alkalies, lime and magnesia must have existed in combination with silica and alumina, forming a mixture which perhaps resembled dolerite, while the very dense atmosphere would contain in the form of acid gases, all the carbon, chlorine and sulphur, with an excess of oxygen, nitrogen and watery vapour. The first action of a hot acid rain, falling upon the yet uncooled crust, would give rise to chlorids and sulphates, with separation of silica; and the accumulation of the atmospheric waters would form a sea charged with salts of soda, lime, and magnesia. The subsequent decomposition of the exposed portions of the crust, under the influence of water and carbonic acid, would transform the felspathic portions into a silicate of alumina (clay) on the one hand, and alkaline bicarbonates on the other; these, decomposing the lime-salts of the sea, would give rise to alkaline chlorids and bicarbonate of lime—the latter to be separated by precipitation, or by organic agency, as limestone. In this way we may form an idea of the generation from a primitive homogeneous mass, of the siliceous, calcareous and argillaceous elements which make up the earth's crust, while the source of the vast amount of carbonate of lime in nature is also explained.*

* Am. Jour. Sci. (2) xxv. 102, and Canadian Journal for May 1858.

When we examine the waters charged with saline matters which impregnate the great mass of calcareous strata constituting in Canada the base of the Silurian system, we find that only about one-half of the chlorine is combined with sodium; the remainder exists as chlorids of calcium and magnesium, the former predominating,—while sulphates are present only in small amount. If now we compare this composition, which may be regarded as representing that of the palæozoic sea, with that of the modern ocean, we find that the chlorid of calcium has been in great part replaced by common salt, —a process involving the intervention of carbonate of soda, and the formation of carbonate of lime. The amount of magnesia in the sea, although diminished by the formation of dolomites and magnesite, is now many times greater than that of the lime ; for so long as chlorid of calcium remains in the water, the magnesian salts are not precipitated by bicarbonate of soda.[*]

When we consider that the vast amount of argillaceous sedimentary matter in the earth's strata has doubtlessly been formed by the same process which is now going on, viz. the decomposition of feldspathic minerals, it is evident that we can scarcely exaggerate the importance of the part which the alkaline carbonates, formed in this process, must have played in the chemistry of the seas. We have only to recall waters like Lake Van, the natron lakes of Egypt, Hungary and many other regions, the great amounts of carbonate of soda furnished by springs like those of Carlsbad and Vichy, or contained in the waters of the Loire, the Ottawa, and probably many other rivers that flow from regions of crystalline rocks, to be reminded that the same process of decomposition of alkaliferous silicates is still going on.

V. A striking and important fact in the history of the sea, and of all alkaline and saline waters, is the small proportion of potash-salts which they contain. Soda is pre-eminently the soluble alkali ; while the potash in the earth's crust is locked up in the form of insoluble orthoclase, the soda-feldspars readily undergo decomposition. Hence we find in the analyses of clays and argillites, that of the alkalies which these rocks still retain, the potash almost always predominates

[*] See Report Geol. Surv. Canada, 1857, pp. 212-214, and Am. Jour. Science (2) xxviii. pp. 170 and 305.

greatly over the soda. At the same time these sediments contain silica in excess, and but small portions of lime and magnesia. These conditions are readily explained when we consider the nature of the soluble matters found in the mineral waters which issue from these argillaceous rocks. I have elsewhere shown that, setting aside the waters charged with soluble lime and magnesia salts, issuing from limestones, and from gypsiferous and saliferous formations, the springs from argillaceous strata are marked by the predominance of bicarbonate of soda, often with portions of silicate and borate, besides bicarbonates of lime and magnesia, and occasionally of iron. The atmospheric waters filtering through such strata remove soda, lime and magnesia, leaving behind the silica, alumina and potash—the elements of granitic and trachytic rocks. The more sandy clays and argillites being most permeable, the action of the infiltrating waters will be more or less complete; while finer and more compact clays and marls, resisting the penetration of this liquid, will retain their soda, lime and magnesia, and by subsequent alteration, will give rise to basic feldspars containing lime and soda, and if lime and magnesia predominate, to hornblende or pyroxene.

The presence or absence of iron in sediments demands especial consideration, since its elimination requires the interposition of organic matters, which by reducing the peroxide to the condition of protoxide, render it soluble in water, either as a bicarbonate or combined with some organic acid. This action of waters holding organic matter upon sediments containing iron-oxide has been described by Bischof and many other writers, particularly by Dr. J. W. Dawson[†] in a paper on the colouring matters of some sedimentary rocks, and is applicable to all cases where iron has been removed from certain strata and accumulated in others. This is seen in the fire-clays and iron-stones of the coal-measures, and in the white clays associated with great beds of green-sand (essentially a silicate of iron,) in the cretaceous series of New Jersey. Similar alternations of white feldspathic beds with others of iron ore occur in the altered Silurian rocks of Canada, and on a still more remarkable scale in those of the Laurentian series. We may probably look

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† Quart. Journ. Geol. Soc., vol. v, p. 25.

upon the formation of beds of iron-ore as in all cases due to the intervention of organic matters, so that its presence, not less than that of graphite, affords evidence of the existence of organic life at the time of the deposition of these old crystalline rocks.

The agency of sulphuric and muriatic acids, from volcanic and other sources, is not however to be excluded in the solution of oxide of iron and other metallic oxides. The oxidation of pyrites, moreover, gives rise to solutions of iron and alumina salts, the subsequent decomposition of which by alkaline or earthy carbonates will yield oxide of iron and alumina; the absence of the latter element serves to characterize the iron-ores of organic origin.‡ In this way the deposits of emery, which is a mixture of crystallized alumina with oxide of iron, have doubtless been formed.

Waters deficient in organic matters may remove soda, lime and magnesia from sediments, and leave the granitic elements intermingled with oxide of iron; while on the other hand, by the admixture of organic materials, the whole of the iron may be removed from strata which will still retain the lime and soda necessary for the formation of basic feldspars. The fact that bicarbonate of magnesia is much more soluble than bicarbonate of lime, is also to be taken into account in considering these reactions.

The study of the chemistry of mineral waters, in connexion with that of sedimentary rocks, shows us that the result of processes continually going on in nature is to divide the silico-argillaceous rocks into two great classes,—the one characterized by an excess of silica, by the predominance of potash, and by the small amounts of lime, magnesia and soda, and represented by the granites and trachytes, while in the other class silica and potash are less abundant, and soda, lime and magnesia prevail, giving rise to pyroxenes and triclinic feldspars. The metamorphism and displacement of sediments may thus enable us to explain the origin of the different varieties of plutonic rocks without calling to our aid the ejections of the central fire.

[‡ Hydrated alumina in the form of gibbsite is however met with incrusting limönite, and the existence of compounds like pigotite, in which alumina is united with an organic substance allied to crenic acid, seems to show that this base may, under certain conditions, be taken into solution by organic acids.]

VI. The most ancient sediments, like those of modern times, were doubtlessly composed of sands, clays, and limestones, although from the principles already defined in IV. and V., it is evident that the chemical composition of these sediments in different geologic periods must have been gradually changing. It is from a too hasty generalization that an eminent geologist has concluded that limestones were rare in earlier times, for in Canada the Laurentian system—an immense series of stratified crystalline rocks which underlie unconformably both the Silurian and the old Cambrian or Huronian systems—contains a limestone formation (interstratified with dolomites), the thickness of which Sir W. E. Logan has estimated at not less than 1000 feet. Associated with this, besides great volumes of quartzite and gneiss, there is a formation of vast but unknown thickness, the predominant element of which is a triclinic feldspar, varying in composition between anorthite and andesine, and containing lime and much soda, with but a small proportion of potash. These feldspars are often mixed with hypersthene or pyroxene; but great masses of the rock are sometimes nearly pure feldspar. These feldspathic rocks, as well as the limestones, are associated with beds of hematitic and magnetic iron-ores, the latter often mixed with graphite. Ancient as are these Laurentian rocks we have no reason to suppose that they mark the commencement of sedimentary deposits; they were doubtlessly derived from the ruins of other rocks in which the proportion of soda was still greater; and the detritus of these Laurentian felspars, making up our palæozoic strata, is now the source of alkaline waters by which the soda of the silicates, rendered soluble, is carried down to the sea in the form of carbonate to be transformed into chlorid of sodium. The lime of the feldspars being at the same time removed as carbonate, these sedimentary strata in the course of ages become less basic, poorer in soda and lime, and comparatively richer in alumina, silica, and potash. Hence in more recent crystalline rocks we find a less extensive development of soda-feldspars, while orthoclase and mica, chlorite and epidote, and silicates of alumina, like chiastolite, kyanite, and staurotide, which contain but little or no alkali, and are rare in the older rocks, become abundant.

The decomposition of the rocks is more slow now than formerly,

because soda-silicates are less abundant, and because the proportion of carbonic acid in the air (an efficient agent in these changes,) has been diminished by the formation of limestones and coal. It will be evident that the principles above laid down are only applicable to the study of rocks in great masses, and refer to the predominance of certain mineral species at certain geologic epochs, since local and exceptional causes may reproduce in different epochs the conditions which belong to other periods.

VII. Mr. Babbage§ has shown that the horizons or surfaces of equal temperature in the earth's crust must rise and fall, as a consequence of the accumulation of sediment in some parts and its removal from others, producing thereby expansion and contraction in the materials of the crust, and thus giving rise to gradual and wide-spread vertical movements. Sir John Herschel‖ subsequently showed that, as a result of the internal heat thus retained by accumulated strata, sediments deeply enough buried will become crystallized and ultimately raised, with their included water, to the melting point. From the chemical reactions at this elevated temperature, gases and vapours will be evolved, and earthquakes and volcanic eruptions will result. At the same time the disturbance of the equilibrium of pressure consequent upon the transfer of sediments, while the yielding surface reposes upon a mass of matter partly liquid and partly solid, will enable us to explain the phenomena of elevation and subsidence.

According, then, to Sir J. Herschel's view, all volcanic phenomena have their source in sedimentary deposits; and this ingenious hypothesis, which is a necessary consequence of a high central temperature, explains in a most satisfactory manner the dynamical phenomena of volcanoes, and many other obscure points in their history, as for instance, the independent action of adjacent volcanic vents, and the varying nature of their ejected products. Not only are the lavas of different volcanoes very unlike, but those of the same crater vary at different times; the same is true of the gaseous matters, hydrochloric, hydrosulphuric, and carbonic acids.

§ " On the Temple of Serapis." Proc. Geol. Soc., vol. ii, p. 73.
‖ Ibid. vol. ii, pp. 548 & 596.

As the ascending heat penetrates saliferous strata, we shall have hydrochloric acid, from the decomposition of sea-salt by silica in the presence of water; while gypsum and other sulphates, by a similar reaction, would lose their sulphur in the form of sulphurous acid and oxygen. The intervention of organic matters, either by direct contact, or by giving rise to reducing gases, would convert the sulphates into sulphurets, which would yield sulphuretted hydrogen when decomposed by water and silica or carbonic acid, the latter being the result of the action of silica upon earthy carbonates. We conceive the ammonia so often found among the products of volcanoes to be evolved from the heated strata, where it exists in part as ready-formed ammonia (which is absorbed from air and water, and pertinaciously retained by argillaceous sediments), and is in part formed by the action of heat upon azotized organic matter present in these strata, as already maintained by Bischof.[*] Nor can we hesitate to accept this author's theory of the formation of boracic acid from the decomposition of borates by heat and aqueous vapour.[†]

The almost constant presence of remains of infusorial animals in volcanic products, as observed by Ehrenberg, is evidence of the interposition of fossiliferous rocks in volcanic phenomena.

The metamorphism of sediments *in situ*, their displacement in a pasty condition from igneo-aqueous fusion as plutonic rocks, and their ejection as lavas with attendant gases and vapours are, then, all results of the same cause, and depend upon the differences in the chemical composition of the sediments, the temperature, and the depth to which they are buried : while the unstratified nucleus of the earth, which is doubtless anhydrous, and according to the calculations of Messrs. Hopkins and Hennessey, probably solid to a great depth, intervenes in the phenomena under consideration only as a source of heat.[‡]

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* Lehrbuch der Geologie, vol. ii, pp. 115–122.

† Ibid. vol i, p. 669.

[‡The notion that volcanic phenomena have their seat in the sedimentary formations of the earth's crust, and are dependant upon the combustion of organic matters, is as Humboldt remarks, one which belongs to

VIII. The volcanic phenomena of the present day appear, so far as I am aware, to be confined to regions covered by the more recent secondary and tertiary deposits, which we may suppose the central heat to be still penetrating (as shown by Mr. Babbage), a process which has long since ceased in the palæozoic regions. Both normal metamorphism and volcanic action are generally connected with elevations and foldings of the earth's crust, all of which phenomena we conceive to have a common cause, and to depend upon the accumulation of sediments and the subsidence consequent thereon, as maintained by Mr. James Hall in his theory of mountains. The mechanical deposits of great thickness are made up of coarse and heavy sediments, and by their alteration yield hard and resisting rocks; so that subsequent elevation and denudation will expose these contorted and altered strata in the form of mountain-chains. Thus the Appalachians of North America mark the direction and extent of the great accumulation of sediments by the oceanic cur-

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the infancy of geognosy (*Cosmos*, vol. v, p. 443. Otte's translation). In 1834 Christian Keferstein published his *Naturgeschichte des Erdkörpers*, in which he maintains that all crystalline non-stratified rocks, from granite to lava, are products of the transformation of sedimentary strata, in part very recent, and that there is no well-defined line to be drawn between neptunian and volcanic rocks, since they pass into each other. Volcanic phenomena according to him have their origin, not in an igneous fluid centre, nor an oxydizing metallic nucleus, but in known sedimentary formations, where they are the result of a peculiar process of fermentation, which crystallizes and arranges in new forms the elements of the sedimentary strata, with evolution of heat as an accompaniment of the chemical process. (*Naturgeschichte*, vol. 1 p. 109, also *Bull. Soc. Géol. de France* (1) vol. vii. p. 197.)

These remarkable conclusions were unknown to me at the time of writing this paper, and seem indeed to have been entirely overlooked by geological writers; they are, as will be seen, in many respects an anticipation of the views of Herschel and my own; although in rejecting the influence of an incandescent nucleus as a source of heat, he has, as I conceive, excluded the exciting cause of that chemical change, which he has not inaptly described as a process of fermentation, and which is the source of all volcanic and plutonic phenomena. See in this connection my paper *On the Theory of Igneous Rocks and Volcanoes*, in the Canadian Journal for May, 1858.]

rents during the whole palæozoic period; and the upper portions of these having been removed by subsequent denudation, we find the inferior members of the series transformed into crystalline stratified rocks.§

[§ The theory that volcanic mountains have been formed by a sudden local elevation or tumefaction of previously horizontal deposits of lava and other volcanic rocks, in opposition to the view of the older geologists who supposed them to have been built up by the accumulation of successive eruptions, although supported by Humboldt, Von Buch, and Elie de Beaumont, has been from the first opposed by Cordier, Constant Prevost, Scrope and Lyell. (See Scrope, *Geol. Journal,* vol. xii, p. 326, and vol. xv. p. 500; also Lyell, *Philos. Trans.* part 2, vol. cxlviii, p. 703, for 1858.) In these will we think be found a thorough refutation of the elevation hypothesis and a vindication of the ancient theory.

This notion of paroxysmal upheaval once admitted for volcanoes was next applied to mountains which, like the Alps and Pyrenees, are composed of neptunian strata. Against this view, however, we find De Montlosier in 1832 maintaining that such mountains are to be regarded as the remnants of former continents which have been cut away by denudation, and that the inversions and disturbances often met with in the structure of mountains are to be regarded only as local accidents. (*Bul· Soc. Geol.,* (1) vol. ii, p. 438, vol. iii, p. 215.)

Similar views were developed by Prof. James Hall in his address before the American Association for the Advancement of Science, at Montreal in August 1857. This address has not been published, but they are reproduced in the first volume of his *Report on the Geology of Iowa,* p. 41. He there insists upon the conditions which in the ancient seas gave rise to great accumulations of sediment along certain lines, and asserts that to this great thickness of strata, whether horizontal or inclined, we are to ascribe the mountainous features of North Eastern America as compared with the Mississippi valley. Mountain heights are due to original depositions and subsequent continental elevation, and not to local upheaval or foldings, which on the contrary, give rise to lines of weakness, and favor erosion, so that the lower rocks become exposed in anticlinal valleys, while the intermediate mountains are found to be capped with newer strata.

In like manner J. P. Lesley asserts that " mountains are but fragments of the upper layers of the earth's crust," lying in synclinals and preserved from the general denudation and translation. (*Iron Manufacturer's Guide,* 1859, p. 53.]